

EVALUATION OF A NEW COCKPIT DEVICE: THE INTEGRATED ELECTRONIC INFORMATION SYSTEM

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In spite of the well-recognized need for complete, accurate, and timely information in the cockpit environment, no computerized information system has been successfully introduced to the commercial flight deck. We suggest that two factors – information integration and multiple search mechanisms – may be identified as necessary characteristics for a viable electronic information system for the cockpit. The use of an information system designed according to these principles was examined during an evaluation of the system at a major US airline. During the controlled experiment segment of the evaluation, subjects performed two sets of similar information retrieval and performance calculation tasks using the system and using traditional paper manuals; response accuracy and task execution time served as the dependent variables. Results showed that for both information retrieval and performance calculations, task execution with the integrated information system was significantly faster and had fewer errors than did task execution using paper manuals. Possible reasons for improved performance are discussed.

INTRODUCTION

Human operators make decisions based on the information they possess at the time the decision is made. Complete, accurate, and timely information is critical for task performance in any environment, particularly so in a high-risk environment such as air transport. In the commercial aviation domain, the list of incidents and accidents in which incomplete, inaccurate, or delayed information plays a role is too long (see, for example, Canadian Aviation Safety Board, 1985; Flight Safety Focus, 1985). Often, the information is not actually lacking, it is instead buried in ambiguously organized text. In one accident, for example, the crew's inability to locate the correct emergency procedure was determined to be a significant contributing factor to the fatal outcome (Flight Safety Focus, 1985). As indicated in the accident report, "The crew apparently believed that the procedure was in the abnormal section, when it was actually in the emergency section."

Although the most apparently obvious solution is the computerization of information in the cockpit, studies which have examined the use of such information systems for the cockpit and for other similarly complex environments have failed to demonstrate their efficacy (Converse, 1995; Rouse & Rouse, 1980; Rouse & Rouse, 1982), and no such commercial system has yet been successfully introduced to the cockpit. We suggest that one contributing factor is that the simple digitization of paper-based manuals and other informative materials is not the solution.

Rather, the extent to which an information system provides integrated information will have a large effect on the efficacy of that system. That is, the simple digitization of information – the reproduction of paper manuals and other paper-based information sources in an electronic format – will be of limited value because it still requires that the user actively recall the organization of the information and the location of the desired information item. Integrated electronic information, in contrast, intelligently links together relevant information items and so provides access to a wider, more comprehensive range of items in every display screen.

An additional factor that may influence the efficacy of a computerized information system is the extent to which the system rigidly prescribes available search strategies by the organization of the information and the mechanism by which an item may be retrieved. A system which forces the user to define his or her search strategy according to the organization of the system is of little use if that organization is unknown or forgotten. This, in fact, was the problem faced by the crew searching for the emergency procedure in the accident described above. A more flexible system that allows the user to retrieve information using more than a single search mechanism enables the user to conduct the search along the dimension most familiar or suitable.

This study was designed to investigate the suggestion that a computerized information system which incorporates information integration and multiple search mechanisms should facilitate task execution. The study was carried out as part of the evaluation of a new computerized information system recently conducted at a major US airline. This system,

known as the ICIS – Integrated Crew Information System, is comprised of individual semi-portable units (one per crewmember) that communicate via a local area network (LAN). The units contain a variety of procedural, operational, and informational applications that provide decision support for the crew (for example, normal and non-normal procedures, aircraft performance data and calculations, manuals, flight planning, moving maps, and charts). See Figure 1. Immediate access to information is facilitated by multiple search mechanisms that allow the user to locate the desired item by name (index), physical location in the cockpit (a graphic virtual cockpit), or by using traditional tables of contents.

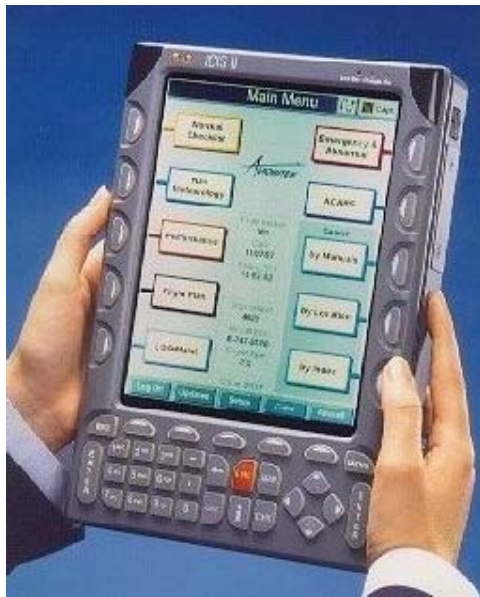


Figure 1. ICIS Unit

One part of the evaluation examined the use of ICIS in a full mission simulator environment; this evaluation is discussed elsewhere (Avionitek, 1998). The second part of the evaluation, which is the focus of this paper, assessed the value of this system for two tasks routinely performed in the cockpit - information search and performance calculations - in a

controlled experimental setting. Specifically, the objective of this study was to examine the comparative use of paper and electronic media (ICIS) for the execution of information retrieval and performance calculation tasks.

METHOD

Participants

20 Boeing 747 crewmembers from a major US airline were recruited and participated in the study. All crew members were male, and were, on the average, 48 years old, had 13,500 flight hours, and used computers several times a week.

Apparatus

Each participant worked individually at a work station which included a desktop computer, ICIS unit, necessary supplemental information (e.g. weather, runway conditions), and all the relevant paper manuals. Tasks were administered using a 'Computer Based Questionnaire (CBQ)', which was presented on a computer screen. This program prompted the participant with sequential information retrieval and performance calculation tasks. The participant responded to each task by either entering a text response, or by pressing a 'skip' key to go on to the next task without providing an answer.

Tasks

The tasks included a variety of information search topics and performance calculation problems. Tasks were chosen for the extent to which their complexity, difficulty, and reliance on external information sources were representative of those found during routine line operation at this airline. The information retrieval tasks required that the participant locate a specific information item in order to respond to the question; performance calculations required that the participant calculate the desired values. The tasks used in the evaluation are listed in Table 1.

Table 1. Sample Evaluation Tasks. (Set A and Set B are matched for content and difficulty in support of the experimental design.)

	Tasks in set A	Tasks in set B	Task type
1.	STORM Light Switch General Information	INS – AUTO/MAN/TEST Switch – General Information	Information retrieval
2.	Driftdown	PTOG Definition	Information retrieval
3.	Precooler Control Systems – MEL	APU Check Valve – MEL	Information retrieval
4.	Take off speeds FLEX calculation – at MSP	Take off speeds FLEX calculation – at ORD	Performance Calculation
5.	Take off speeds slippery runway calculation – at MSP	Take off speeds slippery runway calculation – at ORD	Performance Calculation

Experimental Design

The intent of this study was to do a direct comparison of the two types of information media, in which each participant would use both the electronic integrated media (ICIS) and paper media for task performance. The experiment, therefore, was a balanced within-subject design, in which the main effect of interest (the independent variable) was the Information Media (ICIS or Paper). The dependent variables were response accuracy (correct, incorrect, or skipped response) and task execution time.

To facilitate this comparison, we developed two sets of functionally identical tasks (set A and set B). During the experiment, each participant performed one set of tasks using Paper documentation and another set of tasks with the ICIS. In order to prevent an order effect for both “Information Media” and “Task”, these two factors were counter-balanced. There were thus four groups of five participants each:

Group 1: set A with ICIS, set B with Paper Documentation.
Group 2: set A with Paper Documentation, set B with ICIS.
Group 3: set B with ICIS, set A with Paper Documentation.
Group 4: set B with Paper Documentation, set A with ICIS.

Procedure

The first part of the experimental session consisted of ICIS training. During this period each participant gained experience using the ICIS to perform information retrieval tasks and calculate takeoff performance values. The final 10 minutes of the training session were used to perform several practice tasks using the CBQ. The Training session took approximately 45 minutes.

Immediately following the training session, the participants performed the experimental tasks: seven information retrieval tasks with Paper and seven with the ICIS. In addition, they performed four performance calculation tasks - two with Paper and two with ICIS. Task execution time and task response outcome were recorded by the CBQ. The task performance session took approximately 45 minutes.

RESULTS

Prior to conducting an analysis of the main factor of interest (Media: Paper, ICIS), separate ANOVAs were conducted for each of the dependent variables to verify that no systematic bias had been introduced by the order of Task Set, or by the Task Set x Media manipulation. In all cases, the “Task Set,” and “Order” main effects were not significant. Further, there was no meaningful interaction of these effects with “Information Media.” These findings indicated that the “Information Media” effect is independent of the “Task set” and “Order” effects. In the following sections we therefore focus only on the effects of the Media factor. The task accuracy variable is discussed first, and then the task execution time variable.

Task Response Outcome

The possible outcome for each task was either correct or incorrect, or no response (skip). While the first two responses are straightforward, the latter (skip) requires some explanation: skip represents a situation in which the participant abandoned the task and moved on to the next task (perhaps because he or she could not find the necessary information).

Overall, 80% percent of the questions were answered correctly, 14% were incorrect and 6% were skipped (no response). Figure 2 presents the relative contribution of Paper Documentation and ICIS to the outcome results.

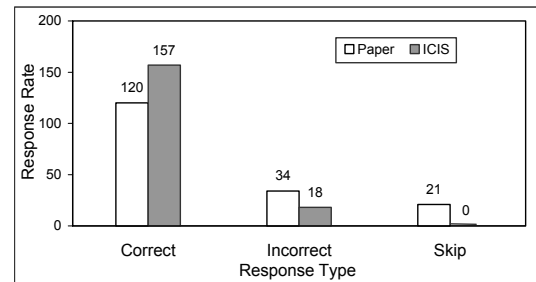


Figure 2. Accuracy of response for Paper and for ICIS. (There were 20 participants, 9 questions for each set, and 10 missing data points for a total of 350 valid values.)

Since each participant performed the tasks both with Paper and with ICIS, a paired t-test, appropriate for the comparison of matched sets, was used for the statistical analysis. The results of the paired t-test, conducted on the percentage of correct response for each participant, indicated a significant effect of Media. The mean of paired difference was 0.21 percent. This difference is significant ($p < .001$). Further, there were almost twice as many incorrect responses in the Paper (34 incorrect responses) as opposed to ICIS (18); and 21 skipped questions in the Paper compared with no (0) skipped in the ICIS.

The pattern of more Correct responses with ICIS and more Incorrect and Skipped responses with Paper Documentation remains constant when information retrieval tasks and performance calculation tasks are examined separately. Tables 1 and 2 present the response frequencies for information retrieval tasks and performance calculations, respectively.

Table 1. Frequency of response for **Information Retrieval Tasks** only.

Response	Condition		Total
	Paper	ICIS	
Correct	95	125	220
Incorrect	20	10	30
Skip	20	0	20
Total	135	135	270

Table 2. Frequency of response for **Performance Calculation Tasks** only.

Response	Condition		Total
	Paper	ICIS	
Correct	25	32	57
Incorrect	14	8	22
Skip	1	0	1
Total	40	40	80

Execution Times

A similar comparison of Paper and ICIS was completed for execution time (Table 3). Since the tasks each crew member performed in both Paper and ICIS condition were matched, we could compare the two Media conditions. A paired t-test, which compares the difference (in task execution times) between using Paper Documentation and ICIS, was again used for the statistical analysis. The mean difference in execution time for correct responses between the Paper and ICIS conditions was 58 seconds. This difference is highly significant ($p=0.0001$).

Table 3. Mean execution times (and standard deviations), for each possible outcome, for each condition (all times in seconds).

Response	Condition	
	Paper	ICIS
Correct	137 (117)	73(61)
Incorrect	167 (120)	89(57)
Skip	272 (130)	-

The effect of using ICIS on task execution time is similar when information retrieval tasks and performance calculation tasks are examined separately:

Table 4. Mean execution times (and standard deviations), for each possible outcome, for each condition – **Information Retrieval Tasks** only (all times in seconds).

Response	Condition	
	Paper	ICIS
Correct	115 (116)	66 (61)
Incorrect	129 (82)	62 (31)
Skip	272 (133)	-

Table 5. Mean execution times (and standard deviations), for each possible outcome, for each condition – **Performance Calculation Tasks** only (all times in seconds).

Response	Condition	
	Paper	ICIS
Correct	221 (83)	100 (55)
Incorrect	221 (147)	130 (65)
Skip	262 (*)	-

* $n=1$ therefore no standard deviation

To summarize, in this analysis we compared the execution times for information retrieval tasks and for performance calculation tasks as carried out with Paper and with ICIS. The results indicate that, overall, task performance using ICIS was significantly faster than task performance using Paper Documentation.

DISCUSSION

The objective of this experiment was to compare the use of paper and electronic media (ICIS) for the execution of information retrieval and performance calculation tasks. To assess the efficacy of media type, two dependent measures were collected: response accuracy (correct, incorrect, skipped response) and task execution time. With respect to response accuracy, it was found that while using the electronic media, pilots made more correct responses (by a factor of 1.3), than with the traditional paper media. The same factor was maintained when the results were broken down by the type of tasks. Task execution with the electronic media was also faster, by a factor of two, than with the paper documentation.

What characteristics of the system may have contributed to differences in task performance? Turning first to information retrieval tasks, we suggest that both the integration of information, and the variety of search mechanisms were possible contributing factors to the increased accuracy of the search and to the increased speed. As noted previously, the information integration inherent in the system afforded the user access to all related items. There was thus much less chance that the participant would respond incorrectly due to incomplete information.

In addition, although we lack the data at this preliminary stage to draw firm conclusions, we propose that the multiple search mechanisms may have allowed the user to conduct the information search in the way most suitable to the user and to the task. For example, individuals who were more spatially oriented or who were more familiar with the physical layout of the cockpit panels may have found the graphic, "virtual cockpit" method of information search to be the most effective, particularly when the task involved a specific control or indicator. Alternately, the index may have been more attractive to verbally-oriented users or in cases in which the task was easily defined by a single, specific word. This characteristic of the system eliminated the need for the user to recall the organization of the information, and so may have enabled him or her to focus solely on the validity of the information itself.

Integration and multiple search mechanisms may also be responsible for the faster execution of the information retrieval tasks. The access to relevant information items was made more immediate by the integration of the items with the task itself. The participant was therefore able to retrieve these information items with fewer steps in the information retrieval process, which speeded the process. Further, the choice of search mechanisms made the information organization less constrictive to the user, which reduced the time needed to locate the desired information.

Similar factors may have contributed to the results of performance calculation tasks. Most obviously, of course, the computerized system was able to carry out the algorithmic performance calculations immediately and accurately. This re-allocation of the task element to the computer eliminated a long and potentially difficult sub-task. Perhaps more importantly, the integrated information provided the participant with immediate access to all the supplemental information (e.g. runway conditions, weather data) needed for the correct performance calculation. The ability to carry out a complex task quickly as well as accurately may have been enhanced not only by computer power, but by computer-aided access to complete and relevant information.

The two tasks considered in this experiment are routinely performed on the flight deck and are important aspects of the efficiency and safety of the flight. Although the contribution of information integration and multiple search mechanisms can remain only suggestions at this preliminary stage, it was shown that while using an electronic media based on these principles pilots made far fewer errors, both in information retrieval and in performance calculations, as well as performed their tasks faster.

In the cockpit, however, locating information or calculating performance values are only two of the many tasks that the crew needs to perform in order to safely and efficiently fly the aircraft. How might these initial findings be applied to other tasks in the cockpit environment?

The findings of this study appear to suggest that the integration of information enables the user to perform (at least some) tasks more quickly and with greater accuracy. Other tasks in the cockpit may also benefit from integrated information. Emergency checklist performance, for example, may be benefited by the ability to easily access supplemental information or other linked procedures (Avionitek, 1998). The use of weather maps will be more efficient if the flight route is superimposed. Flight planning may be optimized if all information relevant to the proposed route (e.g. Notices to Air

Men – NOTAMS, weather, airport data, etc) is immediately available.

The need for electronic information systems for the cockpit environment and other complex environments has not yet been translated into an effective design. This study was a first attempt to determine whether an information system which provided integrated information and multiple search mechanisms might serve as a useful system for the airline cockpit. Future research might serve to define more specific rules by which information items should be integrated, and more closely examine the nature of the search mechanisms. Finally, it appears doubtful that information integration and multiple search mechanisms are a panacea for all cockpit tasks. An important research goal will be the determination of the task characteristics or types which can most benefit from this addition to cockpit information display.

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